Glossary

Cross-References Appear in *Italics*

25 Manhattan Engineer District code for uranium-235; from 92-U-235

49 Manhattan Engineer District code for plutonium-239; from 94-Pu-239

Activation energy Generic term for energy that must be supplied to cause a reaction to happen; see also *Fission barrier* and *Coulomb barrier*. In nuclear reactions, activation energies are usually expressed in millions of electron volts (*MeV*).

AEC Atomic Energy Commission (United States). Succeeded by the Nuclear Regulatory Commission (*NRC*).

ALAS Association of Los Alamos Scientists. Superseded by Federation of American Scientists (*FAS*).

Alpha (α) decay Natural radioactive decay mechanism characteristic of heavy elements such as radium and uranium in which a nucleus ejects an alpha-particle, which is a nucleus of helium-4. Notationally designated by ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$, or ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + \alpha$, where X and Y designate so-called parent and daughter nuclei.

Ångstrom Unit of length equivalent to 10^{-10} meters; one ten-billionth of a meter. Characteristic of the effective sizes of atoms.

Atomic number (*Z*) Number of protons in the nucleus of an atom. Identifies the chemical element to which the atom belongs.

Atomic weight (*A*) The weight of an atom in atomic mass units; see Sects. 2.1.4 and 2.5. The symbol A is also used to designate the *nucleon number,* the total number of protons plus neutrons within a nucleus.

Barn (bn) Unit of reaction cross-section equivalent to 10^{-24} cm^2 = 10^{-28} m^2.

Baruch plan A plan for control of nuclear materials and weapons submitted by the United States to the United Nations in June 1946. Named after Bernard Baruch, U. S. representative to the United Nations Atomic Energy Commission. Despite months of debate, the plan was never implemented; Chap. 9.

B. C. Reed, *The History and Science of the Manhattan Project*,
Undergraduate Lecture Notes in Physics, DOI: 10.1007/978-3-642-40297-5,

Becquerel (Bq) A unit of rate of radioactive decay; 1 Bq = 1 decay per second. See also *Curie*.

Beta (*β*) decay Natural radioactive decay mechanism of nuclei that are neutron or proton-rich. If a nucleus is neutron-rich, a neutron spontaneously transmutes into a proton plus an electron, ejecting the latter to the outside world: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e^{-}$, where X and Y designate parent and daughter nuclei. In this case, known as β^{-}decay (with the electron known as a β^{-} particle), the daughter nucleus is one element heavier in the Periodic Table than the parent nucleus. Conversely, if a nucleus is proton-rich, a proton spontaneously decays into a neutron and an *positron*, ejecting the latter to the outside world: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{1}e^{+}$; in this case ($\beta^{+}$ decay) the daughter nucleus is one element lighter in the Periodic Table than the parent nucleus. A sequence of such decays may follow until the nucleus achieves stability.

Binding Energy A form of energy which is created from mass, and which can be transformed back into mass; Sects. 2.1.4 and 2.5. In reactions where the mass of the output product(s) is less than that of the input reactants, binding energy is said to be liberated ($E = mc^2$), and the energy appears in the form of kinetic energy of the products and/or one or more of the products being in an "internally excited" energy state. If the mass of the output products is greater than that of the input reactants, kinetic energy from the input reactants is transmuted into mass. See also *Mass defect* and *Q-value*.

Bockscar Name of the B-29 bomber which carried the Nagasaki *Fat Man* nuclear weapon.

B-Pile First large-scale (250 MW) nuclear reactor constructed at the Hanford Engineer Works (*HEW*, Washington) for the purpose of breeding plutonium. B-pile began operation in late 1944, and was soon followed by the D and F piles at the same site; Chap. 6.

Calutron A device based on a *Cyclotron* which is used for separating isotopes of different atomic weights by ionizing them and passing them through a strong magnetic field; Sect. 5.3. A contraction of *Cal*ifornia *U*niversity cyclo*tron*. See also *Mass spectroscopy*.

CEW Clinton Engineer Works, Tennessee. Location of Manhattan Project uranium enrichment facilities; Chap. 5.

CIW Carnegie Institution of Washington.

Combined Policy Committee (CPC) American-British-Canadian committee established in August, 1943, to coordinate nuclear research and to serve as the focal point for interchanging information; Sect. 7.4.

Control rod Device made of a neutron-absorbing material that is used in a nuclear reactor to control the reaction rate. Cadmium and boron are excellent neutron absorbers.

Coulomb barrier Amount of kinetic energy that an "incoming" nucleus which is approaching a "target" nucleus must possess in order to overcome the repulsive electrical force between protons within the two nuclei in order to collide and induce a nuclear reaction with the target nucleus. Typically measured in millions of electron volts (*MeV*); Sect. 2.1.8.

CP-1 Critical (or Chicago) Pile number 1, the first nuclear reactor to achieve a self-sustaining nuclear chain reaction. This uncooled, graphite-moderated device operated for the first time on December 2, 1942; Sect. 5.2.

Critical mass Minimum mass of a fissile material necessary to achieve a self-sustaining fission chain reaction, taking into account loss of neutrons through the surface of the material. If the material is not surrounded by a neutron-reflecting tamper, the term "bare" critical mass is used. For uranium-235 and plutonium-239, the bare critical masses are respectively about 45 and 17 kg; Sect. 7.5.

Cross-section A quantity which measures the probability that a given *nuclide* will undergo a particular type of reaction (fission, scattering, absorption …) when struck by an incoming particle. Cross-sections are expressed as areas in *barns*, where 1 barn $= 10^{-24}$ cm^2, and are usually designated by the symbol σ along with a subscript designating the type of reaction involved. Cross sections depend on the type of particle being struck, the type of striking particle, and the energy of the striking particle; Sect. 2.4.

Curie (Ci) A unit of rate of radioactive decay; 1 Ci $= 3.7 \times 10^{10}$ decays per second. This is the alpha-decay rate of one gram of freshly-isolated radium-226. See also *Becquerel*.

Cyclotron A modified mass spectrometer (see *Mass spectroscopy*) used for accelerating electrically charge particles to very great energies by the use of electric and magnetic fields; Sect. 2.1.8. See also *Calutron*.

Diffusion Generic term for the passage of particles through space. The speed of the particles depends on their mass and the temperature of the environment. In the Manhattan Project, uranium was enriched by both gaseous and thermal diffusion processes; Sects. 5.4 and 5.5.

Dragon machine Colloquial name for an experimental device developed at Los Alamos wherein a slug of uranium-235 would be dropped through a hole in a plate of uranium-235, momentarily creating a fast-neutron fission chain reaction; Sect. 7.11.

D-T Reaction Fusion of deuterium and tritium to produce helium and a neutron: ${}_1^2H + {}_1^3H \rightarrow {}_0^1n + {}_2^4He$; Sect. 9.2.

Electron capture A decay mechanism wherein an inner-orbital electron is captured by a nucleus. The captured electron combines with a proton to form a neutron, rendering the process as a reverse β^- decay, equivalent to a β^+ decay.

Enola Gay Name of the B-29 bomber which carried the Hiroshima *Little Boy* nuclear weapon.

Enrichment Generic term for any process which alters the abundance ratio of isotopes in a sample of some input feed material. Usually used in the sense of a process which increases the number of fissile uranium-235 nuclei in comparison to the number of non-fissile uranium-238 nuclei. In the Manhattan Project, both electromagnetic and diffusion enrichment techniques were employed; Chap. 5.

eV Electron-volt. A unit of energy equivalent to 1.602×10^{-19} Joules. Chemical reactions typically involve energy exchanges of a few eV. See also *MeV*.

FAS Federation of American Scientists.

Fat Man Code name for the Nagasaki implosion-type plutonium bomb, which achieved an explosive *yield* of about 22 kt.

First criticality Moment in the detonation of a nuclear weapon when the core first achieves conditions necessary for a self-sustaining chain reaction.

Fissile A fissile material is one whose nuclei will undergo fission when struck by bombarding neutrons of any energy. Uranium-235 and plutonium-239 are both fissile. Fissile is a subset of *Fissionable*. See also *Fission barrier*.

Fission Nuclear reaction wherein a nucleus splits into two roughly equal fragments, typically accompanied by a significant release of energy ($\sim$200 MeV). Fission may be induced by striking the nucleus with an outside particle (usually a neutron), but also happens spontaneously in some heavy elements. Compare *Fusion* below.

Fission barrier Minimum amount of kinetic energy a bombarding neutron must possess in order to induce fission in a target nucleus. Typically measured in millions of electron volts (MeV); Sect. 3.3. For nuclei of elements in the middle of the Periodic Table the fission barrier can be as high as $\sim$55 MeV, but for heavy nuclei such as those of uranium atoms is on the order of 5–6 MeV, depending on the isotope involved. In these latter cases the barrier may be low enough to be exceeded by the *binding energy* liberated upon neutron absorption, rendering a nuclide *fissile*.

Fissionable A fissionable material is one whose nuclei can be made to fission when struck by bombarding neutrons. In practice, the term is usually reserved for materials that fission only under bombardment by "fast" neutrons, typically of kinetic energy $\sim$1 MeV or greater. Compare to *Fissile* above. Uranium-238 is fissionable, but not fissile.

Franck report Document prepared by University of Chicago scientists in June, 1945, addressing political and social problems associated with nuclear weapons; Sect. 8.4. Now considered a founding document of the nuclear non-proliferation movement. See also *Jeffries report*.

Frisch-Peierls memorandum Memorandum prepared in early 1940 by Otto Frisch and Rudolf Peierls at Birmingham University, which alerted British government authorities to the possibility of fission bombs. Sect. 3.7.

Fusion Nuclear reaction wherein two nuclei "fuse" to form a heavier nucleus, typically accompanied by an energy release of a few or few tens of MeV. Used in fusion weapons, which are known colloquially as "hydrogen bombs." Fusion reactions liberate less energy than fission reactions, but liberate more energy per mass of reactant nuclei, and often generate particles which can catalyze further fission and fusion reactions; Sect. 9.2. Compare to *Fission* above.

General Advisory Committee (GAC) An advisory committee to the Atomic Energy Commission, established to provide advice on technical issues; Sect. 9.1.

Greenhouse George First United States test of a radiation implosion weapon, May 1951. Yield 225 kt; Sect. 9.2.

Half-life Characteristic time required for one-half of the nuclei of a naturally-decaying isotope to undergo a specified decay process. Half-lives vary from tiny fractions of a second to billions of years.

Heavy water A form of water in which the hydrogen atoms are replaced with deuterium, an isotopic form of hydrogen. Chemical symbol D_2O. D designates a deuterium, or "heavy hydrogen" nucleus, ${}^{2}_{1}H$. Heavy water occurs naturally, and can be extracted from ordinary water. Heavy water is of interest in nuclear power and research as it makes an excellent neutron *moderator*.

HEW Hanford Engineer Works, Washington state. Location of Manhattan Project plutonium production facilities; Chap. 6.

Hex Colloquial term for uranium hexafluoride, UF_6.

Hibakusha Japanese term for people who survived both the Hiroshima and Nagasaki bombings.

IAEA International Atomic Energy Agency.

ICBM Inter-Continental Ballistic Missile.

Implosion A chemical explosion which is directed "inwards". In the context of nuclear weapons, used to crush an initially sub-critical mass to critical density; Sect. 7.11.

Initiator Device at the core of a nuclear weapon that releases neutrons to initiate the chain reaction. In the Manhattan Project, initiators were also known as Urchins.

Interim Committee Advisory group established by Secretary of War Henry Stimson in May, 1945, to advise on postwar atomic-energy planning; Sect. 8.4.

Isotope See also *Nuclide*. Nucleus or atom of an element that has the number of protons characteristic of the element (*Atomic number*), and some specific number of neutrons. All nuclei of a given element have the same number of protons, but different isotopes of an element have different numbers of neutrons. Different isotopes of a given element consequently have different *Atomic weights*.

Ivy King Largest pure fission weapon ever detonated by the United States, November, 1952. Yield ~500 kt; Sect. 9.2.

Ivy Mike First true American thermonuclear (fusion) weapon, detonated November 1952. Yield ~10.4 Mt; Sect. 9.2.

Jeffries report A document prepared by University of Chicago scientists in late 1944 describing anticipated postwar research and industrial applications in the area of nuclear energy; Sect. 8.2. Also known as the "Prospectus on Nucleonics." See also *Franck report*.

Joe-1 Western term for the first test of a Soviet nuclear weapon, 1949; Sect. 9.2.

Jumbo Name of a 200-ton steel vessel that was intended to be used to contain the first test explosion of a nuclear weapon. Jumbo was never used, and parts of it still remain at the *Trinity* site; Sect. 7.12.

K-25 Code name for the gaseous diffusion plant at the Clinton Engineer Works (*CEW*); Sect. 5.4.

Kiloton (kt) A unit of energy equivalent to that released by the explosion of 1,000 metric tons of conventional explosive (1 metric ton = 1,000 kg), commonly used to quantify the energy *yield* of nuclear weapons; 1 kt = 4.2×10^{12} Joules = 1.17 million kWh. World War II-era nuclear weapons had yields in the 10–20 kt range.

kWh kilowatt-hour, a unit of energy corresponding to a power consumption (or generation) of 1,000 Watts (= 1,000 Joule/sec) over a time of 1 h (3,600 s). 1 kWh = 3.6×10^6 Joule.

Lewis Committee There were various Lewis Committees during the Manhattan Project, all involving MIT chemical engineer Warren Lewis. The most important ones reviewed the entire atomic-energy program at the time the CP-1 reactor went critical in late 1942 (Sect. 4.10), and the proposed research program at Los Alamos in March/April 1943 (Sect. 7.2).

Little Boy Code name for the Hiroshima gun-type uranium fission bomb, which achieved a *yield* of about 13 kt.

LTBT Limited Test-Ban Treaty. 1963 treaty which prohibits nuclear weapons tests or any other nuclear explosions in the atmosphere, outer space, or under water. Does not prohibit underground tests; Sect. 9.4.

Mass defect Difference in mass between an "assembled" nucleus and the sum of the masses of the individual protons and neutrons that comprise it; usually expressed in equivalent energy units. All stable nuclei have masses less than the sum of the masses of their constituent *nucleons;* Sects. 2.14 and 2.5.

Mass spectroscopy An experimental technique for determining masses of atoms to high precision. Ionized atoms or molecules are directed into a region of space containing a magnetic field. The trajectories of the particles consequently depend on their mass; by noting where particles "land", masses can be accurately measured; Sect. 2.1.4. See also *Cyclotron* and *Calutron*.

MAUD committee British government committee established in response to the *Frisch-Peierls memorandum* to investigate possible military uses of nuclear fission; Sects. 3.7 and 4.4. In a July, 1941, report (Sect. 4.4) the committee analyzed the possible use of uranium in a fission bomb.

May-Johnson bill Legislation concerning atomic energy introduced to the United States Congress in October, 1945; Sect. 9.1. The bill's harsh control and security provisions generated considerable criticism within the scientific community, which led to its being abandoned in favor of the *McMahon bill*.

McMahon bill Legislation which established the United States Atomic Energy Commission; Sect. 9.1.

Mean Free Path (MFP) Average distance that a particle will travel through some material before striking another particle and possibly inducing some reaction. In the context of nuclear weapons, usually applied to the passage of neutrons through a sample of fissile material; Sect. 7.5. Commonly designated by the symbol λ.

MED Manhattan Engineer District of the United States Army; Sect. 4.9.

Megaton (Mt) A unit of energy equivalent to that released by the explosion of one million metric tons of conventional explosive, commonly used to quantify the energy release of extremely powerful nuclear weapons. 1 Mt $= 4.2 \times 10^{15}$ Joules $=$ 1.17 billion kWh.

Metallurgical Laboratory Code name for the atomic research laboratory at the University of Chicago, directed by Arthur Compton. This laboratory had particular responsibility for development of nuclear reactors and plutonium-separation chemistry.

MeV Mega electron-volt; one million electron-volts. A unit of energy equivalent to 1.602×10^{-13} Joules. Nuclear reactions typically involve energy exchanges of a few MeV. See also eV.

Military Policy Committee (MPC) Established in September, 1943, by Secretary of War Henry Stimson to advise on development and use of nuclear weapons. The MPC acted as a sort of Board of Directors of the Manhattan Project; Sect. 4.10.

Moderator Material within a nuclear reactor which slows high-energy neutrons to "thermal" velocities (Sect. 2.4) to increase their chance of fissioning U-235 nuclei. Graphite and heavy water make excellent moderators. Ordinary water can also be used, but requires a reactor fueled with enriched uranium.

MW Megawatt (one million Watts). A unit of power for quantifying the rate of consumption of energy. 1 Watt = 1 Joule/sec.

NAS National Academy of Sciences (United States).

NDRC National Defense Research Committee. Established by President Roosevelt in June, 1940, to support and coordinate research conducted by civilian scientists which might have military applications. The Uranium Committee was absorbed into the NDRC when the latter was established (Sect. 4.2). Absorbed into the *OSRD* in June, 1941.

Neutron Electrically neutral constituent particle of atomic nuclei. Given the number of protons in the nucleus (*Atomic number*), the number of neutrons in a nucleus dictates the *isotope* of the element involved. Neutrons can be thought of as a form of "nuclear glue" that holds nuclei together against repulsive electrostatic forces that protons exert on each other.

Neutron number (*N*) Number of neutrons within a nucleus. The number of neutrons N plus the number of protons Z (*Atomic number*) totals to the *Nucleon number A*. See also *Atomic weight*.

NBS National Bureau of Standards (United States).

NPT Acronym for the Treaty on the Non-Proliferation of Nuclear Weapons (1968); Sect. 9.4.

NRC National Research Council; Nuclear Regulatory Commission (United States).

NRL Naval Research Laboratory (United States).

Nucleon Collective term for neutrons and protons.

Nucleon number (*A*) Total number of protons plus neutrons within a nucleus, always an integer number. See *atomic number* and *neutron number*.

Nuclide Generic term for a nucleus of a given number of protons and neutrons. Notation: ${}^{A}_{Z}X$, where X is the symbol for the element involved, Z is the number of protons (*Atomic number*), and A is the total number of protons plus neutrons (*Atomic weight*). Essentially synonymous with *Isotope*, except that use of the latter term is usually in the context of referring to nuclides of a given element, which will all have the Z same value but different atomic weights.

Nucleus Positively-charged core of an atom, comprising protons and neutrons.

OSRD Office of Scientific Research and Development. Established by President Roosevelt in June, 1941, to coordinate research and development of devices that might be of military value (e.g., radar, proximity fuses, fission weapons).

Overpressure Condition of atmospheric pressure above "normal" atmospheric pressure, caused by the detonation of a nuclear weapon, usually measured in pounds per square inch (psi); Sect. 7.13.

P-5 The "primary five" nuclear weapons states: United States, Russia, Britain, France, China.

Parity Oddness or evenness of the number of protons and neutrons in a nucleus; Sect. 3.2. In non-proliferation parlance, the relative evenness of numbers of nuclear weapons held by various countries.

Pile Historic term for a nuclear reactor.

Planning Board The Manhattan Project involved two Planning Boards. The first was established in November, 1941, to develop recommendations concerning plans for production of fissile materials and contracts for engineering studies; Sect. 4.6. The second was at Los Alamos, organized to coordinate technical work at the laboratory; Sect. 7.2.

Positron A positively charged electron, also known as a beta-positive (β^+) particle.

Predetonation Detonation of a nuclear explosive before the bomb core is fully assembled, resulting in an explosive *yield* less than intended. May be caused by neutron-emitting impurities or spontaneous fissions; Sect. 7.7.

Project Alberta Code name for Los Alamos program to prepare bombs for combat.

Proton Constituent positively-charged particle of atomic nuclei. The number of protons in a nucleus is equal to the *Atomic number* of the nucleus.

***Q*-value** Amount of energy liberated or consumed in a nuclear reaction, typically measured in millions of electron volts (MeV); Sect. 2.1.6.

Queen Marys Colloquial name for plutonium-processing facilities at the Hanford Engineer Works (*HEW*); Sect. 6.5. These 800-foot-long buildings rivaled the ocean liner Queen Mary in length (1,020 feet).

RaLa Abbreviation for the "radiolanthanum" implosion diagnostic technique developed at Los Alamos; Sect. 7.11.

Reaction channel One of a number of possible outcomes in a reaction involving two (or more) input particles. With neutron-induced reactions involving light elements, a number of possible channels can occur; Sect. 2.4.

Rem Unit of radiation exposure; "Radiation Equivalent in Man." Synonymous with *Roentgen;* Sect. 7.13. For humans, a single-shot dose on the order of 500 rems will often result in death.

Reproduction factor Measure of the net number of neutrons generated per each consumed in a nuclear reactor, designated by the symbol k. If $k \geq 1$, a self-sustaining reaction is in progress.

Roentgen See *Rem*.

S-1 Committee; S-1 Section New name acquired by the *Uranium Committee* after it was absorbed into the Office of Scientific Research and Development (*OSRD*) when the latter was established in July, 1941 (Sects. 4.4, 4.5).

S-1 Executive Committee Successor to the S-1 Committee established June, 1942, within the *OSRD* to coordinate research into various methods of fissile-material production; Sect. 4.9. Chaired by James Conant, the other members were Lyman Briggs, Ernest Lawrence, Harold Urey, Arthur Compton, and Eger Murphree.

S-50 Code name for the thermal diffusion plant at the Clinton Engineer Works (*CEW*); Sect. 5.5.

Scientific Panel A subcommittee of the *Interim Committee* (1945) established to provide advice on technical issues related to the use and future development of nuclear weapons; Sect. 8.4. Members were Robert Oppenheimer, Arthur Compton, Enrico Fermi, and Ernest Lawrence. Another Scientific Panel was that appointed to advise on postwar atomic policies; Sect. 9.1.

Second criticality Moment in the course of the detonation of a nuclear weapon where the core has expanded to the point where conditions necessary for a self-sustaining chain reaction no longer hold.

SED Special Engineer Detachment; a group of military personnel with technical and scientific training; Sect. 7.3.

SF Spontaneous fission.

SLBM Submarine-Launched Ballistic Missile.

Smyth Report Colloquial title of a report authored by Henry Smyth and issued by the United States government just after the bombings of Hiroshima and Nagasaki in August, 1945; Sect. 8.7. This document was the first public description of the Manhattan Project; its full tile was "Atomic Energy for Military Purposes: The Official Report on the Development of the Atomic Bomb under the Auspices of the United States Government, 1940-1945".

SODC Standard Oil Development Company.

SORT Strategic Offensive Reductions Treaty (2001); Sect. 9.4.

START Strategic Arms Reduction Treaty (1991, 1993 and 2010); Sect. 9.4. There are multiple START treaties between the United States and Russia.

Tamper A heavy (usually metallic) structure that surrounds the core of a nuclear weapon, designed to reflect escaping neutrons back into the core and briefly retard expansion of the core while it explodes. Both effects act to increase weapon efficiency.

Target Committee Group of military officers and scientists established April, 1945, to advise on targeting of nuclear weapons against Japanese cities; Sect. 8.1.

Top Policy Group Committee of government, military, and scientific personnel established by President Roosevelt, October, 1941, to advise on policy considerations raised by nuclear issues; Sect. 4.5.

Trinity First test of a nuclear weapon, July 16, 1945, in southern New Mexico. This implosion device achieved a yield of about 22 kt.

TVA Tennessee Valley Authority, an agency of the United States government.

Uranium Committee Formally, the Advisory Committee on Uranium, established October, 1939, to investigate possible military applications of nuclear fission; Sect. 4.1. This was the first United States government group convened to consider the possibility of fission weapons and nuclear power. The Uranium Committee was absorbed into the *NDRC* in June, 1940, and became known as Section S-1 of the Office of Scientific Research and Development (*OSRD*) when the latter was established in July, 1941 (Sect. 4.4).

USSBS United States Strategic Bombing Survey; Sect. 8.6.

X-10 Code name for the graphite reactor at the Clinton Engineer Works (*CEW*); Sect. 5.2.

Xenon poisoning Xenon is a product of nuclear fissions; as it accumulates within a reactor, it "poisons" the reaction due to its tendency to absorb neutrons; Sect. 6.5. If not for the short half-life involved (9 h), the responsible isotope, Xe-135, would continue to accumulate until the reaction could not longer proceed.

Y-12 Code name for the electromagnetic separation complex at the Clinton Engineer Works (*CEW*); Sect. 5.3.

Yield Energy released by a nuclear weapon, usually measured in *kilotons* (kt) or *megatons* (Mt)

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